

EFFECTS OF SURFACE ON TRIPLE HOP DISTANCE AND KINEMATICS

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ABSTRACT

Background: The single leg triple hop (SLTH) test is often utilized by rehabilitation practitioners as a functional performance measure in a variety of patient groups. Accuracy and consistency are important when measuring the patient progress and recovery. Administering the SLTH test on different surfaces, consistent with the patient's sport, may affect the hop distances and movement biomechanics.

Purpose: The purpose of this study was to examine the effects of court and turf surfaces on the hop distance, limb symmetry index (LSI), and lower extremity kinematics of a SLTH test.

Methods: Recreationally active female participants ($n = 11$, height 163.8 ± 7.1 cm, mass 63.1 ± 7.1 kg, age 18.9 ± 0.9 yrs), without injury, volunteered to participate in the study. Three maximal effort SLTH test trials on two different surfaces (court, synthetic turf) were collected and analyzed using 3D motion analysis techniques. Outcome variables included SLTH test distances and LSI values and sagittal plane kinematics including trunk, hip, knee and ankle range of motion (ROM) during the last two landings of each SLTH test trial. The second landing involves an absorption phase and propulsion phase in contrast to the final landing which involves absorption and final balance on the single leg. Paired t-tests were used to determine differences between surfaces in hop distance and LSI values. Two-way repeated measures ANOVA were used to determine differences between surfaces in kinematic variables.

Results: The total SLTH test distance was not statistically different between the court (4.11 ± 0.47 m) and turf (4.03 ± 0.42 m, $p = 0.47$) surfaces. LSI for the court surface was $100.8 \pm 3.0\%$ compared to $99.7 \pm 3.0\%$ for turf surface, which was not statistically different ($p = 0.30$). Knee flexion ROM was significantly less ($p = 0.04$) on the turf compared to the court surface during the second landing. Ankle flexion range of motion was also significantly less ($p = 0.03$) during the second landing on turf compared to court.

Conclusions: Type of surface influenced landing kinematics but not total SLTH test distance. When evaluating the quality of landings during a SLTH test, it may be warranted to observe each type of landing and the type of surface used during single leg tests.

Keywords: biomechanics, landing, motion analysis, movement system, rehabilitation, return to sport

Level of Evidence: 2

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INTRODUCTION

It is estimated that 200,000 anterior cruciate ligament (ACL) injuries occur in the United States each year.¹ Of those injured, 90% will undergo surgical ACL reconstruction (ACLR), typically resulting in rehabilitation for 6-12 months.² Rehabilitation focuses on improving strength and symmetry during functional tasks that begin in an isolated environment and progress toward simulating sport activity. A large percentage (94%) of athletes return to some level of sport, less than half at their previous level of competition, when surveyed between one and two years following ACLR.³ However, Paterno et al.⁴ reported that 29.5% of athletes who had ACLR, and were cleared to return to sport, suffered a second ACL injury within 24 months after they returned to sport. Further, 30% of those second ACL injuries occurred within the first twenty athletic exposures after return to sport.⁴ Objective return to sport assessments and passing certain criterion is recommended to potentially reduce the risk of second ACL injury.⁵

One of the main physical performance tests used to inform the return to sport decision is a battery of single leg hop tests. The single-leg triple hop (SLTH) is part of this test battery and typically interpreted based on the calculation of a limb symmetry index (LSI) that compares the injured to the non-injured limb. An LSI of at least 90% is generally considered a sufficient threshold for return to sport.^{5,6} The SLTH test consists of three hops on a single limb for a maximal distance with a controlled landing on the final hop. There is some merit to using the LSI as a SLTH outcome measures as poor hop symmetry is predictive of an individual not playing sport two years post-injury.⁷ In addition to these performance outcome measures, the SLTH test also allows clinicians to qualitatively assess movement patterns and potential identify high-risk movement strategies such as dynamic lower extremity valgus⁸ and stiff-legged landings.^{9,10} Consistent testing methodology is important when measuring recovery progress or improvement with performance training. However, different surfaces may need to be employed in clinical or applied settings which may lead to altered hop distances or landing kinematics.

Clinically, the SLTH test is typically performed whenever clinicians have enough space for the athlete.

This may be on a carpeted or tiled outpatient clinic setting, or on an athletic playing surface, such as a hardwood or synthetic court surface, natural grass, or artificial turf. However, the surface can significantly alter individual performance and biomechanics. McNitt-Gray et al.¹¹ found that a stiff mat surface resulted in greater knee flexion in gymnasts during drop landings compared to a soft mat surface. Other studies¹²⁻¹⁴ have reported significant differences in movement and loading during a variety of movements on different surfaces. Myers et al.¹² reported normative SLTH test data from a large cohort of high school and college aged athletes that were tested on a court, rubber, or turf surface. Biomechanical differences between surfaces have been previously identified during dynamic cutting type movements and with mechanical impact attenuation testing.^{13,14} The differences of these movements on various surfaces may indicate that there would also be kinematic differences between surfaces during a SLTH test. These differences may suggest that the surface chosen to perform a SLTH test may influence results, ultimately impacting the return to sport decision and/or progression of rehabilitation programs. Since testing may occur on a variety of surfaces commonly found in physical therapy clinics and sport performance centers, quantifying the differences in SLTH test performance would inform clinical decisions regarding return to sport. The purpose of this study was to examine the effects of a hardwood court and a synthetic turf surfaces on the hop distance, limb symmetry index (LSI), and lower extremity kinematics of a SLTH test. Results from this study will better help guide clinicians as they administer return to sport testing batteries after ACL or lower extremity injury.

METHODS

Participants

Recreationally active, injury-free, collegiate-aged females were recruited to participate in the study ($n=11$, height 163.8 ± 7.1 cm, mass 63.1 ± 7.1 kg, age 18.9 ± 0.9 yrs). Potential participants were screened for eligibility and provided informed written consent approved by the High Point University Institutional Review Board. Inclusion criteria consisted of 1) history of playing high school multi-directional sports (e.g. soccer, basketball, lacrosse), 2) currently

active in recreational activities, and 3) no current medical restrictions which would limit participation in running and jumping tasks and no history of lower extremity surgery. Prior to testing, height and body mass were collected for each participant using a standard stadiometer and self-reported limb dominance was identified by asking the participant their preferred leg to kick a soccer ball.

Instrumentation

Participants were instrumented for biomechanical analysis with 43 retro-reflective markers (Figure 1). Standard footwear (adidas adipure 360.2; adidas International, Inc., Portland, OR) was provided to all

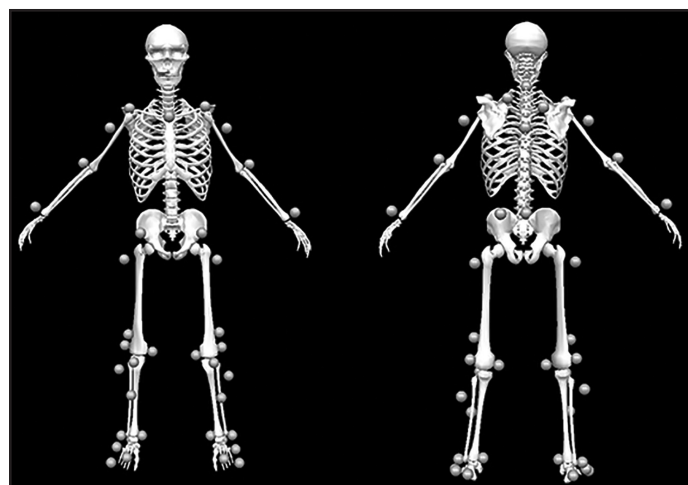


Figure 1. 3D Marker Locations. Anatomical landmarks at the sternum, sacrum, left PSIS, C7, three tracking markers on the upper back, and bilaterally on the shoulder, upper arm, elbow, wrist, ASIS, greater trochanter, mid thigh, medial and lateral knee, tibial tubercle, mid shank, distal shank, medial and lateral ankle, heel, posterior lateral foot, anterior lateral foot, and toe.

participants. Three-dimensional motion data were collected with twelve digital high-resolution cameras (Raptor-12, Motion Analysis Corporation, Santa Rosa, CA) at 200 Hz. The capture volume was optimized to include the second and third landings of the SLTH test. A static trial with the participant in anatomical position with foot placement standardized was collected to determine each participant's neutral alignment and anatomically define each body segment, by which subsequent biomechanical measures were referenced.

Procedures

Participants performed the SLTH test on both court (maple wooden basketball; Bio-Cushion Classic Robbins Sport Surfaces, Cincinnati, OH), and synthetic turf (2.9 cm tufted pile, Polytex® USA, Calhoun, GA) surfaces. They were instructed to complete at least two, and no more than four practice trials on each surface. These practice trials were used to approximate the participants hopping distance to determine the start position for the participant. The starting position was important to ensure the participant's second and final landings were in the motion analysis capture volume. While the surfaces were large enough for all three landings, the capture volume was only able to be best optimized for two landings. Therefore, the second and third landings were collected as they require different requirements. The second landing involves an absorption phase and propulsion phase in contrast to the final landing which involves absorption and final balance on the single leg. Participants were instructed to perform three consecutive maximal forward hops on the same limb without hesitation (Figure 2). Other than a stable third and final landing, holding for two

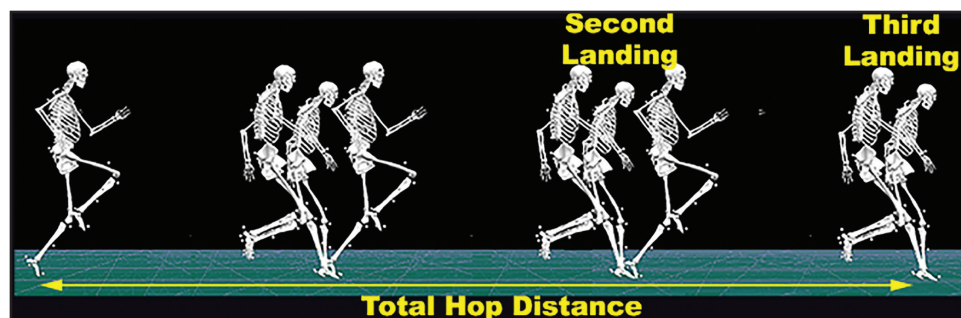


Figure 2. Single leg triple hop (SLTH) test. Three consecutive maximal forward hops on the same limb without hesitation were performed. The second and third landings were analyzed kinematically.

seconds, no restrictions were placed on arm movement or required landing technique.¹⁵ Trials were repeated if the participant lost balance or contacted the ground with their opposing leg at any instance throughout the test. Each participant completed three successful SLTH test trials on each limb. The order of performance, including limb and surface were randomized for all participants.

Data Analysis and Reduction

Total distance hopped was measured as the distance travelled from the toe marker during initial take off to toe marker after landing over the course of the three maximal hops. Distance hopped in the three trials were averaged for the dominant (limb used to kick a ball the furthest) and non-dominant limb, and used to calculate the LSI (non-dominant hop distance/dominant hop distance x 100%). Kinematic data were analyzed in Visual3D (Version 5, C-Motion Inc., Germantown, MD). Hip, knee and ankle joint centers were calculated as previously described from anatomically placed markers.¹⁶ Biomechanical data from both lower extremities and trunk¹⁷ were processed using MATLAB software (version 8.0, The Mathworks, Natick, MA). Initial foot contact for the second and third landings was unable to be determined using foot and ankle data since participants adopted either heel or toe landings during the SLTH test; thus, initial contact was defined as the time of maximal downward pelvic velocity.¹⁸ The end of the landing phase was determined by the lowest vertical position of the sacral marker.¹⁸ The sacral marker method is similar to other methods which identify whole body center of mass displacement from segmental masses or force platforms.¹⁹ Biomechanical variables of interest included the excursion (maximum – minimum values) of ankle, knee, hip, and trunk sagittal joint angles during the deceleration landing phase of the second and third landing.

Statistical Analysis

All statistical analyses were performed using R programming language (version 3.6.0, R Foundation for Statistical Computing, Vienna, Austria). The average distance and lower extremity kinematics of the three successful trials was used for analyses. Distance hopped was not statistically different (court: $p=0.41$; turf: $p=0.70$) between dominant and non-dominant

limb, therefore, only the non-dominant limb was analyzed in subsequent analyses as this limb is often used in studies when compared to a patient group with an involved limb injury.^{20,21} Paired t-tests were used to determine statistical significant differences between surfaces in hop distance and LSI values. Two-way repeated measures (surface and joint) ANOVA were used to test for significant interactions and main effects during each landing ($p<0.05$). Post-hoc analyses were performed with Bonferroni adjustments and Cohen's d effect sizes were calculated for each statistical comparison. Interpretations of effect sizes were operationally defined as trivial (< 0.20), small (≥ 0.20 to < 0.50), medium (≥ 0.50 to < 0.80), and large (≥ 0.80).

RESULTS

The total hop distance on the non-dominant limb was not statistically different ($p=0.47$) between the court ($4.11 \pm 0.47\text{m}$) and turf ($4.03 \pm 0.42\text{m}$) surfaces. SLTH test LSI for the court surface was $100.8 \pm 3.0\%$ compared to $99.7 \pm 3.0\%$ for turf surface, which was not statistically different ($p=0.30$).

Trunk, hip, knee and ankle total joint excursion are presented in Figure 3. During the second landing, a significant interaction (joint, surface, $p=0.02$) and main effects for joint ($p<0.001$) and surface ($p=0.01$) were found. Post-hoc analysis indicated significant differences ($p<0.05$) in the surfaces during the second landing at the knee and ankle (Figure 3). Specifically, there was significantly greater ($p=0.04$, large effect size 0.94) knee excursion on the court surface ($34.9 \pm 5.3^\circ$) compared to turf surface ($31.7 \pm 5.8^\circ$). Similarly, there was significantly greater ($p=0.03$, large effect size 1.03) ankle excursion on the court ($25.6 \pm 7.8^\circ$) compared to turf ($22.7 \pm 7.4^\circ$) surface. The trunk range of motion was not statistically different, however, a trend with a medium effect size during the court landing compared to turf surface (court $6.6 \pm 2.5^\circ$, turf $5.4 \pm 2.0^\circ$, $p=0.11$, effect size 0.77). Surface differences were not found in hip flexion (court $9.8 \pm 2.3^\circ$, turf $9.6 \pm 2.6^\circ$, $p=0.79$, effect size 0.08). During the final landing, a significant interaction ($p=0.66$) and main effect of surface ($p=0.46$) were not statistically significant for trunk, hip, knee and ankle excursion. Figure 3 illustrates the between participant comparison of each surface during the final landing.

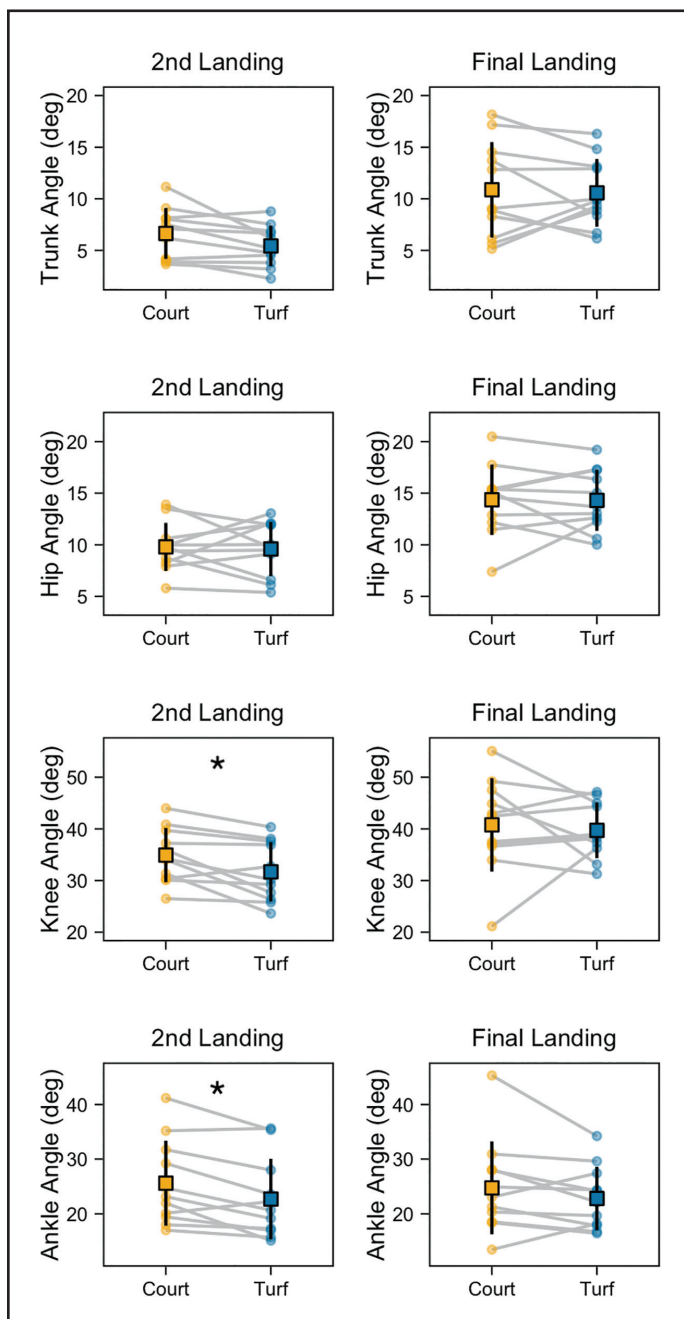


Figure 3. Effect of surface on second and final landing for trunk, hip, knee, and ankle excursion during the landing phase. Gray lines indicate the individual change for each participant when comparing court and turf surfaces. Dot represents each participant and square represents mean with standard deviation black error bar.

* $p < 0.05$ post-hoc analysis indicated significant differences in the surface.

DISCUSSION

The purpose of this study was to examine the effects of court and turf surfaces on the hop distance, limb symmetry index (LSI), and lower extremity kinematics of a SLTH test. There was not a statistically

significant difference in total distance hopped or LSI values across both surfaces. However, on the more cushioned turf surface, decreased knee and ankle motion were found during the second landing of the SLTH test. The movement strategy to reduce ROM may relate to joint stiffening on a softer surface. During the second landing, an absorption phase and propulsion phase are required in contrast to the final landing which involves absorption and final balance on the single leg. Complex joint kinematic and kinetic modulation is evident during landing on different surfaces.^{11,22-25} For instance, when a softer surface is used during landing, individuals will adopt a stiffer landing/hopping style.²⁶ However, kinematic changes at the knee may not be as apparent with slight changes in surface and could be modulated primarily through ankle joint mechanics.²² Additionally, a recent study found no differences in scoring of errors during a drop vertical jump task on three different surfaces.²⁷ However, kinematics were not analyzed and the scoring is likely not sensitive enough to identify joint kinematic differences that we found in the current study.

There was less than 2% difference between the LSI for the court and turf surface which is smaller than the previously established minimal detectable change score and not considered a significant difference in hop distance between the two surfaces.²⁸ The LSI would need to have a difference of at least 10.02% to show a detectable change in distance jumped between the court and the turf.²⁸ Reinjury after an ACLR is common among athletes.⁴ Return to sport protocols for ACLR often include the SLTH test.²⁹ It was thought that reinjury may be due to the fact that the athlete may have had a LSI >90% on one surface, but may have had poor kinematics and <90% LSI on the athlete's playing surface. The results from this study demonstrate that LSI was not affected between the court and the turf surfaces in healthy participants. This suggests that if only LSI was being considered for return to sport, the court and turf surfaces could be used interchangeable for testing. However, kinematic differences may exist, and quality of movement should be considered in addition to measured distances.

The only significant kinematic differences between surfaces that were found were specific to the knee

and ankle flexion and occurred during the second landing of the SLTH test. Knee flexion during the second landing of the SLTH test was found to be greater on the court surface compared to the turf surface. Trigsted et al.³⁰ reported in a group of females (ages 18-25) with ACL reconstruction had less knee flexion ($56.0 \pm 11.2^\circ$) compared to a control group ($64.9 \pm 10.6^\circ$) during a single leg hop for distance (surface not described). Females, with intact and reconstructed ACLs, were reported to have less knee flexion than males during a jump-cut maneuver landing on single leg.³¹ Decreased knee flexion, could increase the risk of a reinjury of the reconstructed graft.³² Deficits in knee flexion could be a contributing factor to reinjury in female athletes who return to sport and is a compensatory strategy to reduce the knee extensor moment and shift proximally to the hip.³³⁻³⁵

Trunk flexion motion was not significantly different but trended (medium effect size) towards greater range of motion on the court compared to the turf. Given our small sample size, further examination of trunk kinematics may be warranted. Blackburn & Padua³⁶ reported that greater trunk flexion produced greater knee and hip flexion during drop landings. Trunk flexion reduces the peak vertical ground reaction force and quadriceps activity, which decreases the load placed on the ACL during ground contact.³⁷ While we did not collect ground reaction force in this study, the increase in trunk flexion may relate to a response to reduce peak ground reaction force and reduce load on the knee and ACL.

Surface type used during SLTH test for return to sport measurements for athletes should also be considered. An athlete should be tested on the surface on which they compete before returning to sport. To reduce risk of injury in ACLR female patients, the SLTH test should be performed first on a surface that promotes increased knee flexion, such as, a hardwood court. After the athlete has shown an LSI of $\sim 90\%$,⁶ it is recommended that the athlete complete the SLTH test on their sport surface. A limitation to the current study was that only a court and turf surface were compared. Some physical therapy clinics may not have access to turf or court but may have a carpet, rubber, or other flooring surfaces. This study can only be generalized to athletes who

participate in sports that compete on turf or court. Further research would need to be completed to look at other athletic surfaces (such as track, grass, sand, tennis court, etc.) to be able to generalize the findings to other sports. Another limitation in the study was that only young healthy adult females were observed. The results found in this study cannot be generalized to males or to females of varying ages. Future studies will need to be conducted to further generalize the SLTH surface comparison results. Future studies should examine ground reaction forces, joint moments, and estimates of ACL loading during the two landing phases of the SLTH test.

CONCLUSIONS

The type of surface tested in this study did not affect SLTH distance; however, surface does influence landing kinematics. This may be important to consider during SLTH testing as patients may use different landing kinematics to hop the same overall distance. Landing kinematics were not consistently different between surfaces from the second to third landing. Joint excursion kinematics, especially during flexion at the knee and ankle, differed between the two surfaces. While small angular differences at the knee and ankle were evident between surfaces, it is still warranted to consider that only healthy participants were involved in the study and ACL injured participants may have greater magnitudes of difference in kinematics on the surfaces. Even though we did not examine ACL injured athletes, decreased knee and trunk flexion on turf surfaces may be especially important to consider in this population. When evaluating the SLTH test, it may be warranted to consider each hop landing and observe the total movement quality and the type of surface used before return to sport.

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